THE INFLUENCE OF MILL WATER ON THE QUALITY OF SUGARCANE JUICE

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By

Ahmad El Fadil Mohamad

Thesis Committee:

Leslie D. Swindale, Chairman
Wayne H. Hilton
Yoshinori Kanehiro
Louis G. Nickell

We certify that we have read this thesis and that in our opinion it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Agronomy.

THESIS COMMITTEE

L. D. Swindale
Chairman

Yoshinori Kanehiro

Louis G. Nickell

H. Wayne Hilton

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INTRODUCTION

The quantity of sugar produced per acre depends not only on the tonnage of cane produced, but also on the sucrose content of the cane. Increasing the sucrose content of the sugarcane by even a small fraction of a per cent will appreciably increase the profit obtained by the cane grower. Research workers in sugarcane are continually struggling to increase the tonnage of cane per acre, and at the same time, to increase the per cent of sucrose in the cane. The goal is a high sugar yield per acre. There are many factors which affect the growth of cane: climate, soil, method and amount of irrigation, and cultural practices are probably the principal ones. Fertilizer is also of great importance. The amount of nutrients in the soil, the availability of those nutrients, and the timing of the applications, have a great effect on the cane and sugar yield.

With mechanized harvesting of cane, a lot of trash and fine soil particles are carried to the factory with the millable cane stalks. A lot of washing has to be done, and a large volume of "mill water" accumulates, to the extent that many new lands are built as a result of the silt deposited from the mill water. This term "mill water" may include also waste water, muds, and silt from any source in the sugar mill. To economize in the use of irrigation water, and to avoid waste disposal problems, many plantations in Hawaii utilize this waste water for irrigation. Some, such as the Waialua Agricultural Company on Oahu, do not ordinarily have much shortage of irrigation water, but the State does not allow waste water from the sugar mills to be run directly into the ocean adjacent to homes and public beaches. They must therefore use the mill water for irrigation. This mill water carries an enormous amount of nutrients to the fields throughout the growing season. As a result, juice quality, which is of prime importance in sugar production, is profoundly affected. The nutrients come partly from the original water and partly from the washed stalks and waste mill products. The reasons for the adverse effects of mill water used in irrigation are unknown, but are most likely related to the amount of nutrient of the mill water, or to the timing of this nutrient application. Possible toxic substances arising from the mill water are likely to cause stunted sugarcane of lowered yield. This does not normally occur in the mill water--irrigated fields.

This thesis investigates the adverse effects of mill water used for irrigation of sugarcane. It is the objective of this research to measure the quality of cane juice in relation to irrigation water sources, and to study the nutritional components of mill water as they may affect sugarcane yield, moisture per cent, and juice quality. This thesis also investigates the general effect of mill water on soil and the different amounts of nutrients, e.g., N, P, K, and S, that could be supplied to the field through the mill water irrigation.

The present research might make possible alterations in nutrient levels required for mill water fields and may indicate that high nutrient-requiring varieties should be grown in these fields. The study of N, P, and K compositions in the first-expressed crusher juice, which is highly related to the available amounts of these nutrients in the soil, can lead to sound fertilizer recommendations. The different relationships that exist between sucrose per cent in the cane and different levels of nutrients applied to the soil with different timing of applications, will also be investigated in this study.

REVIEW OF LITERATURE

Basic Problem of Sugarcane Nutrition

The study of optimum mineral nutrition, in order to ensure the capacity of the cane plant to produce the maximum tonnage of sugar per acre, continues to attract research efforts in many countries. Basic facts on the nutrition of sugarcane are continually being revealed by scientists from studies on the uptake, distribution, and utilization of essential elements.

A great deal of experimental work has been conducted by the Hawaiian Sugar Planters' Association (hereafter referred to as H.S.P.A.), and compiled by Baver (1960) under the title, "Plant and Soil Composition Relationships as Applied to Cane Fertilization". Baver tried to clarify and bring out some of the high correlations existing between plant and soil analyses that makes for good fertilizer recommendations.

The Problem of Juice Quality

Das (1936) mentioned that when we speak of juice quality becoming poorer as a result of heavy fertilization, we usually have in mind the concentration of sucrose in the juice. This concentration was considered by him to be the result of two things--the amount of sucrose present and the amount of water present. Thus we might have the same amount of sucrose in two plants, but if the amount of water was different in the two, the concentration of sucrose will be different. Again, we might have actually more sucrose in one plant than in the other, but due to greater water content the concentration might still be less in the first than in the second. Borden (1936) believed that the higher cane yields had a poorer quality ratio (tons of net cane estimated as required to produce 1 ton of 97.5 pol sugar) than the average yields, but that this fact in itself might be of little economic importance. Das (1931) agreed with the physiologist's idea that in the formation of new protein material such as leaves, tissue, etc., the nitrogenous amino acids brought up by the roots combine with carbohydrates. Naturally the greater the amount of nitrogen conveyed by the roots, the more will be the requirement of carbohydrate. As a result, comparatively small amounts will be stored by the plant as sugar. By applying a heavy dose of nitrogen, the storage capacity of the plant is increased, but leaving less sugar to be stored. The result is that a cane low in sugar will be harvested.

Nitrogen Nutrition of Sugarcane

In a study of nitrogen requirements of sugarcane, Stanford and Ayres (1964) reported that it appeared that different sugarcane varieties possess essentially the same internal N requirements per ton of dry matter at near maximum yield of cane. With nitrogen-insensitive varieties, the internal N requirements associated with near maximum yield of cane may be the same as those associated with optimum sugar yield. Nitrogen sensitive varieties, which show deterioration in quality from excessive N, may have higher internal requirements for maximum cane yield than that corresponding to maximum sugar yield. In general, it appeared to Stanford and Ayres that the nitrogen uptake most often associated with near maximum yield of cane and sugar lay in the range of 3.8 to 4.2 pounds N/ton dry matter. The requirement may be sensibly designated as being approximately 4 pounds N/ton dry matter. They also said that at the final harvest (20th-24th month), millable cane comprises about 65% of the total above-ground material produced on a dry-weight basis; and that the millable stalk varies only slightly from 30% dry matter. Thus 4 pounds total N uptake/ton dry matter corresponds closely to 2 pounds N/ton millable cane.

In the study of the influence of nitrogen on the yield and sucrose content of sugarcane, Alexander (1928) mentioned that more cane per ton of sugar was required when cane was fertilized with nitrogen to offset the depressing effect on sucrose content. Extra cane yields usually offset the lower sucrose content. Borden (1939) had assumed that high glucose was associated with high N in the juice, which in turn was the effect of high nitrogen in the fertilizer. From the experiments conducted on three Oahu plantations to determine the effect of rates and timing of nitrogen fertilizer on cane quality and yields of cane and sugar, Stanford (1963) found that approximately 95% of the maximum yield of sugar was achieved by application of 200 pounds N per acre. In comparison with 200 pounds, applications of 400 and 600 N per acre tended to increase yields of cane and distinctly reduced pol per cent cane. The average yield of sugar was slightly greater for 400 than for 200 pound applications, and slightly less for 600 than for 400 pound N application. Large applications of N as late as 12 months consistently exerted an adverse influence on pol per cent cane and per cent purity of juice. Borden (1940) found significant results indicating that too much N can be harmful to cane yield as well as to cane quality. Baver (1960) found that N fertilizer increases the reducing sugar composition of the cane plant.

Several significant interactions between the amounts of nitrogen and the time of its application were indicated by Borden (1940). He found that with a low level of nitrogen the efficiency was best when the total amount was split one-fourth and three-fourths and applied at 1 and 3 months, respectively. With a medium level of N, the best sugar yield was made when the total amount was split into four equal amounts and applied at 2 month intervals. However, Borden found that with a high level of N applied in either three or four doses, the cane yields were satisfactory but the juice quality was poorer and the recoverable sugar considerably below that secured from the medium level. Stanford (1963) found that reduction in quality was associated both with increased rates and with delayed application of N. Large applications of N as late as 12 months consistently exerted an adverse influence on pol per cent cane and per cent purity of juice.

Ortega _et al_. (1963) found that juice purity and sugar yields per acre were highest when all the nitrogen was applied within the first 4 months, irrespective of whether the amount was divided into two or three differently timed applications, or applied all at once. When part of the N was kept back until the 6th or 8th month, the sugar yield was distinctly lower although the cane yield was approximately the same for all treatments. Baver (1960) found that the N composition of the plant at any given age in the first season of growth depends upon the method of fertilization, and that the N composition at harvest approaches the same values except when comparing late application of higher amounts of N with lower amounts.

Potassium Nutrition of Sugarcane

Together with N and P, K is regarded as one of three major plant food nutrients. It assumes a particularly important role in the nutrition of the sugarcane plant. The demand upon the soil for this nutrient was claimed by Dillewijn (1952) to run to over 800 pounds per acre. Borden (1941) mentioned that sugarcane plant is a great lover of K and if it had the opportunity to do so, will consume large quantities of this nutrient. In connection with the formulation of a sound policy on K fertilization, Borden insisted on differentiating between K uptake by the cane and its requirement for optimum yields, because a luxury consumption of K by the cane plant had been clearly shown. Ayres (1937) said that out of the principal mineral nutrients, K and Si were taken up to the greatest extent by the cane plant. Baver (1960) mentioned that due to the effect of N fertilizers on the K composition of the plant, about 400 pounds K_2O were required to counterbalance the repressive effect of 150 pounds of N. This was on a soil where there was no response to K fertilization. He found that the K content of plants growing on soils that had higher amounts of available K decreased more rapidly with N fertilization than in the case of plants growing at lower K levels.

In the study of the influence of potash on the yield and sucrose content of sugarcane, Borden (1936) stated that sugarcane yields were directly related to the supply of available K, when P was not a limiting growth factor. Samuels (1955) in his experiments in Puerto Rico found that when N was omitted from the cane fertilizer, there was an average reduction of 30% in cane tonnage for all field experiments. When K was omitted the yield reduction averaged only 7%. The reduction due to omission of P was 4%. The response in cane tonnage to potash was usually higher for ratoons. Again Samuels et al. (1952) found that a direct linear relationship existed between the percentage increase in yield and the percentage increase in sucrose concentration, as both factors were influenced by K application, for sugarcane in Puerto Rico. It appeared, therefore, that the application of K fertilizer to sugarcane will not appreciably increase the sucrose content of the cane if it did not increase cane tonnage yields at the same time.

Hance et al. (1934) found that the volume of water used per crop in irrigation of Hawaiian cane lands and the tonnage of Na and K salts thus carried to these areas run into figures of astounding magnitudes. They found that Hawaiian waters pumped from wells carry to an acre of land amounts of K varying from 53 to 1,521 pounds of K_2O. The concentration of K was dependent entirely upon the source from which the water originates.

Phosphorus Nutrition of Sugarcane

The standard amount of P fertilizer applied in most of the plantations in Hawaii varies from 200 to 300 pounds per acre. Gumaste (1960) in his large-scale trials, showed that there was no apparent over-all benefit from application rates of P up to 450 pounds per acre, although some yields increased, maturity was delayed and sucrose content was reduced. Yang (1964), in Taiwan, found that application rates of 75, 112.5 and 150 kilograms of P_2O_5 per hectare, did not increase cane yields but raised the P_2O_5 content of the juice.

Borden (1936) indicated that a low phosphate percentage in the juice would be likely to indicate a low availability in the soil, and a high P in the juice, a high soil availability. Walker (1922) suggested the possibility of using the phosphoric acid content in cane juice as an indication of the amount of phosphoric acid in the soil. The amount of K_2O in the juice was also held to be a measure of the amount of potassium in the soil. Yang (1964) found a logarithmic relationship between level of phosphate application and juice content. Humbert (1962) concluded that there was a complete lack of correlation between available soil phosphorus and sheath phosphorus.

In influence of phosphate on yield and sucrose content of sugarcane, Borden (1936) found that both P and K in the crusher juice showed an adverse relationship to the purity of the juice. He also stated that greater cane yields were found associated with crusher juice containing more than 0.04 per cent P than where less than this amount was present.

Relationship Between Water and Sugarcane Yield in Hawaii

According to experiments carried out by Robinson *et al*. (1963), a series of lysimeter investigations had indicated that moisture removal from a cane field proceeds at approximately the same rate as evaporation from a U. S. Weather Bureau pan. The timing of irrigation applications was determined with reference to the net evaporation from the pan. When these intervals were adjusted to a constant population, the differences in yield of six irrigation interval treatments reflected differences in stalk length. A decrease in stalk length resulted from soil moisture tensions which exceeded 2 bars at the 12 inch depth. However, when the soil moisture tension in any cycle did not exceed 2 bars, an increased rate of elongation following irrigation compensated for the decrease in rate prior to irrigation, and no real reduction in the average growth rate occurred. After the 2 bars stress was exceeded at the 12 inch depth, a real reduction in the average growth rate occurred. Thus Robinson et al. (1963) recommended the application of water to sugarcane before soil moisture tension reaches 2 bars at the 12 inch depth.

Penman (1952) observed that the rates of the annual evapotranspiration from a short grass to pan evaporation should be about 0.75. Robinson explained the difference between this value and the ratio of 1:1 obtained with sugarcane, at least in part, by the roughness of the cane top surface in the field and the resultant increase in turbulent transfer of water vapor in and above the cane.

MATERIALS AND METHODS

Most of the millable cane samples were provided by the H.S.P.A., who also carried out the harvesting and sampling. Crusher juice, soil, and water samples were all taken by the Waialua Agricultural Company.

Materials

Crusher juice was taken from the Waialua Agricultural Company Mill. Samples were taken twice a day, one at 6 a.m. and the other at 3 p.m. A 1-week set of samples were accumulated in the mill freezing box before they were brought to the Department of Agronomy and Soil Science of the University of Hawaii. Other samples of the juice were extracted from the millable cane samples. The millable cane was first chopped into small pieces and then squeezed under a Carver laboratory press. Millable cane was harvested by hand from the burned cane. All the remains of leaves and tops were removed. Both suckers and primaries were included in the millable cane. Irrigation water samples were taken from hydroseparator tanks and from running canals where water was just entering the field. Soil samples were taken from Field Gay 4 of the Waialua Agricultural Company. Approximately 9-inch depth samples were taken from both furrow and ridge with a screw auger.

Preparation of Samples

Juice samples were kept frozen in a freezing box until it was time for analyses. The juice was then thawed and filtered through a cheesecloth. The millable cane samples were chopped into small pieces and kept in a freezing box until it was removed to the University. The samples were dried at 65° C in a blower oven for 4-6 days. Samples were then ground in a Wiley Mill. Soil samples were air-dried, and then sieved with different size screens to meet requirements of different chemical analysis.

Methods of Analysis

Total solids: Total solids in the juice were determined by the spindle method and expressed as brix.

Pol: The method used by the H.S.P.A. for the determination of pol and fiber in cane was as follows: A sample of approximately 900 grams of chopped cane was put into the disintegrator and 2000 ml of water were added. A 10-minute period was allowed for disintegration, after which a sample of the liquid was withdrawn and analyzed for total solids and a saccharimeter reading. By referring to Table II of The Official Methods of the Hawaiian Sugar Technologists (1955), the pol reading was obtained. The fiber was put into a pan with screen bottom, washed thoroughly, pressed, and dried.

Reducing sugars: The method used for the determination of reducing sugars in the cane juice was the volumetric method of Lane and Eynon (1925). In principle, the method involves the determination of the volume of the juice required to reduce completely a measured volume of alkaline copper sulphate solution. The end point was indicated by the reduction of methylene blue to methylene white by a minute excess of reducing sugar.

Sucrose: It was determined by the double inversion method. Ten ml of the juice in which the reducing sugars were already determined were placed in a 100 ml flask. About 40 ml water and 10 ml 6.24 N HCl were added. The flask was then heated in a hot water bath (75° C) to 65° C. The juice was then cooled and neutralized by 6 N NaOH, using phenolphthalein solution as an indicator. The solution was then made to volume and titrated against alkaline copper sulphate (5 ml) for total reducing sugars determination. The sucrose content of the sample was calculated from the difference between the invert-sugar content before and after hydrolysis.

Total N in soil, plant, water, and juice was determined by the Kjeldahl method modified to include nitrate. Organic and nitrate nitrogen were converted into ammonium sulphate and the ammonium distilled into boric acid indicator solution and titrated with standard H_2SO_4 (N = 0.015).

In the case of the juice, only 10 ml was taken for digestion, more than this amount was found to interfere with the digestion procedure. The irrigation water was partially evaporated before it was digested.

Cation exchange capacity was determined by saturating the exchange complex of 25 grams of air-dried soil (20 mesh) with NH_4^+ from 1 N NH_4OAc (buffered to pH 7.0). The NH_4^+ was then replaced with 4% KCl and measured.

Phosphorus was determined colorimetrically as the phosphomolybdate blue complex. Available phosphorus in the soil was extracted with 0.02 N H_2SO_4 containing 3 grams of $(NH_4)_2SO_4$ per liter (Ayres, 1952). The plant and juice were digested with 2:1 nitric-perchloric acid.

Potassium was determined using Beckman flame spectrophotometer.

Sulphur was determined by the modification of the method of Chesnin and Yien (1950). Ten ml of the juice was partially evaporated, then digested in 10 ml of 2:1 nitric perchloric acid. A suitable aliquot was then taken in a 25 ml erlenmeyer flask, 1 gram of $BaCl_2$ crystals was added to develop turbidity and 1 ml gum arabic was added to neutralize the acidic effect. The turbidity was then measured colorimetrically.

Crop logging ripening procedure: Weekly sheath samples were taken and moisture determination was made. The sheath moisture from this analysis was plotted in a ripening log. On the vertical axis of this log was given the range in sheath moisture readings from approximately 70 to 84%. On the horizontal axis was the time line covering a period of about 5 to 7 months, and ending on the estimated date of harvest. A diagonal line was drawn between 83% moisture on the left and 73% at the date of harvest on the bottom right. This diagonal line was called the moisture line and represents the approximate path that the sheath moistures for this crop were expected to follow, rendering this particular field ripe for a specified date of harvest.

RESULTS AND DISCUSSION

Crusher Juice

Crusher juice samples were taken at the mill from eight fields of the Waialua Agricultural Company. Three of these fields were under mill water irrigation. The rest received only pump water irrigation. Variety 50-7209 was grown in all the fields except Gay 9 which contained mixed varieties.

Field Gay 3

This field was planted on July 30, 1963 and harvested on July 27, 1965. The irrigation water used in this field was 60% mill water with the remainder fresh water. The amounts of fertilizer applied were: 283 lbs N/acre, 198 lbs P/acre, and 368 lbs K/acre. Gay 3 received, as all the others did, about 30.5 rounds of irrigation during the 2-year growing season. Each round averaged about 6.7 acre inches. According to the irrigation water analysis (Table IX), this field must have received about an additional 400 lbs N/acre, 200 lbs P/acre, 1200 lbs K/acre and 1500 lbs S/acre through the mill water irrigation during the growing season. Together with the applied fertilizer the field received about 683 lbs N/acre, 398 lbs P/acre and 1568 lbs K/acre. Probably a large amount of K is leached from the soil, and a great portion of the P and N are fixed, but still what remains as available in the soil will lead to an enormous amount of nutrients. Hance et al. (1934) found that Hawaiian waters carry to an acre of land amounts of K varying from 53 to 1521 pounds K_2O. The concentration of K was dependent entirely upon the source from which the water originated.

Table I shows the results of the crusher juice analysis and yield for this field. Out of the eight fields Gay 3 gave the highest ton cane per acre, but the lowest juice purity and sucrose per cent. The amounts of P and K in the juice were very high, approximately double the amounts found in pump water fields. The result followed Borden's formula (1936) that high soil-nutrients availability=high cane yields-low purity-high percentage of nutrients in the juice. The total N in the juice was not proportionately high like the P and K, but was higher than all the rest of the fields except field Ranch 1. It should be noted however that this small difference in N might have more effect on quality than P and K. Gay 3 required the highest tonnage of cane (9.68) needed to produce 1 ton of sugar. More cane tonnage was required in this field and those like it to offset the depressing effect of the low sucrose in order to achieve maximum sugar output. Borden (1936) believed that higher cane yields had a poorer quality ratio than the average yields, but this fact in itself might be of little economic importance. The percentage of reducing substances in the juice was not high. It was less than the average for all fields. This does not agree with Borden's (1939) assumption that high glucose was associated with high N in the juice.

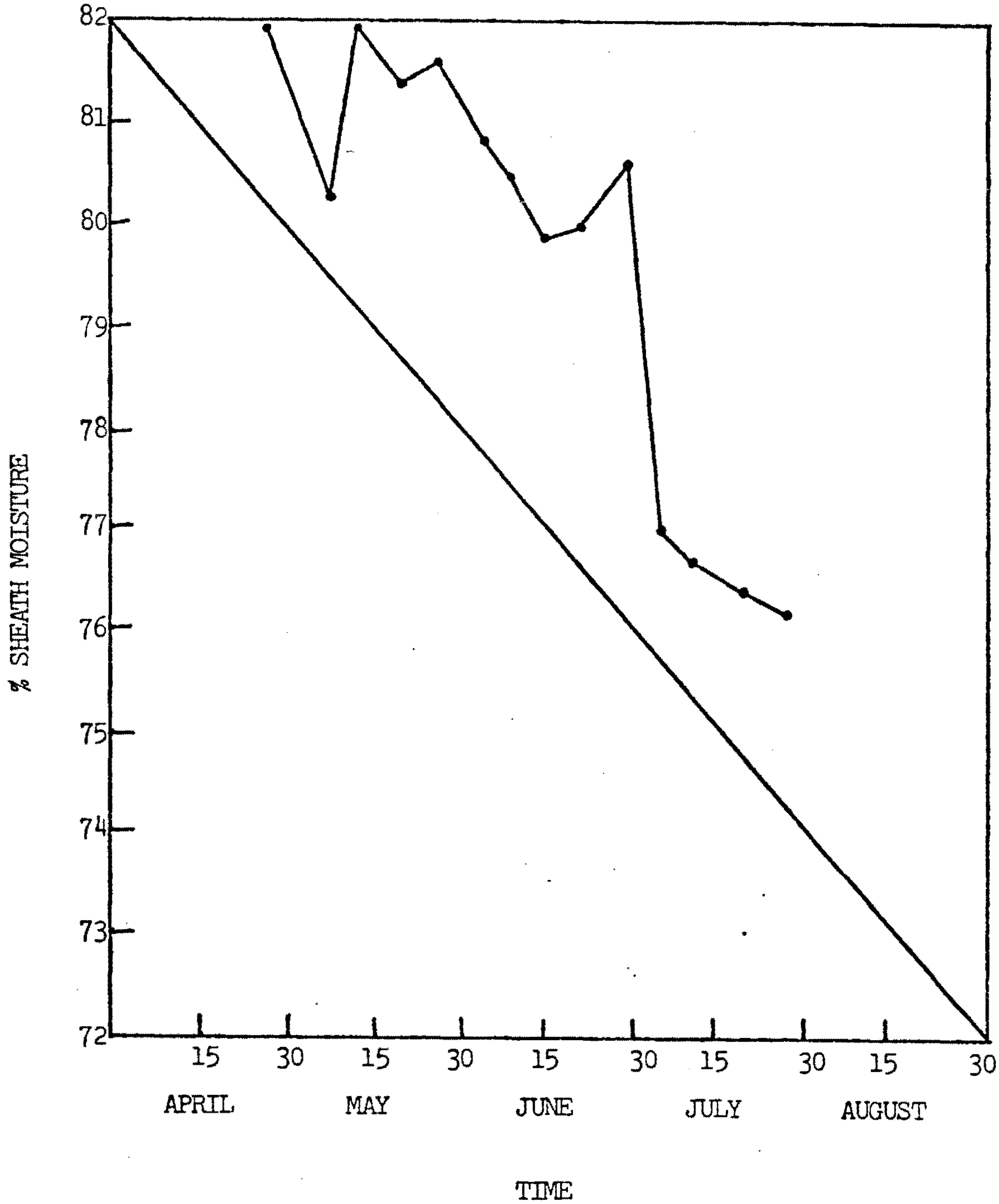
Figure 1 shows the ripening procedure for this field. It is clear from the graph that the cane in this field retained a high moisture content even though water (as irrigation) was withdrawn. Even at harvest time the moisture did not go below 76%. It is probable that the high nutrients in the soil applied throughout the crop growth induced a luxurious vegetative growth and thus increased the moisture per cent of the cane.

TABLE I. ANALYSIS OF CRUSHER JUICE FROM FIELD GAY 3
WITH VARIETY 50-7209 (60% MILL WATER)

Samples	Brix %	Pol %	Purity %	Reducing Substances %	Sucrose %	N ppm	P ppm	K ppm	Tc/Ts (ton cane per ton sugar)	TSPA (ton sugar per acre)	TCPA (ton cane per acre)
1	12.45	10.35	83.0	0.47	11.00	247	196	2300	10.43		
2	13.27	11.08	83.4	0.45	10.68	312	200	2420	9.28		
3	14.37	12.40	86.1	0.36	11.25	320	188	2480	9.85		
4	12.17	10.10	82.9	0.38	9.85	303	238	2760	10.45		
5	13.96	11.71	83.9	0.36	10.82	327	210	2560	9.73		
6	14.54	12.54	86.1	0.36	9.98	242	168	1920	9.19		
7	14.00	12.09	86.3	0.39	10.35	213	156	2080	9.61		
8	15.40	13.53	87.8	0.36	11.64	279	200	2320	8.27		
9	13.15	11.58	85.9	0.36	11.28		168	2510	9.62		
10	14.30	12.18	85.1	0.34	11.53		182	2270	9.97		
11	13.83	11.22	81.3	0.43	11.15		234	2160	10.17		
12	15.23	13.01	85.4	0.45	10.55		240	2560	9.55		
Average	13.89	11.81	84.77	0.39	10.84	280	198	2362	9.68	14.36	134.73

Planting date: 7-30-63 Date of harvest: 7-7-22-65

FIGURE 1. RIPENING PROCEDURE FOR FIELD GAY 3, VARIETY: 50-7209
(60% MILL WATER)



Field Gay 9

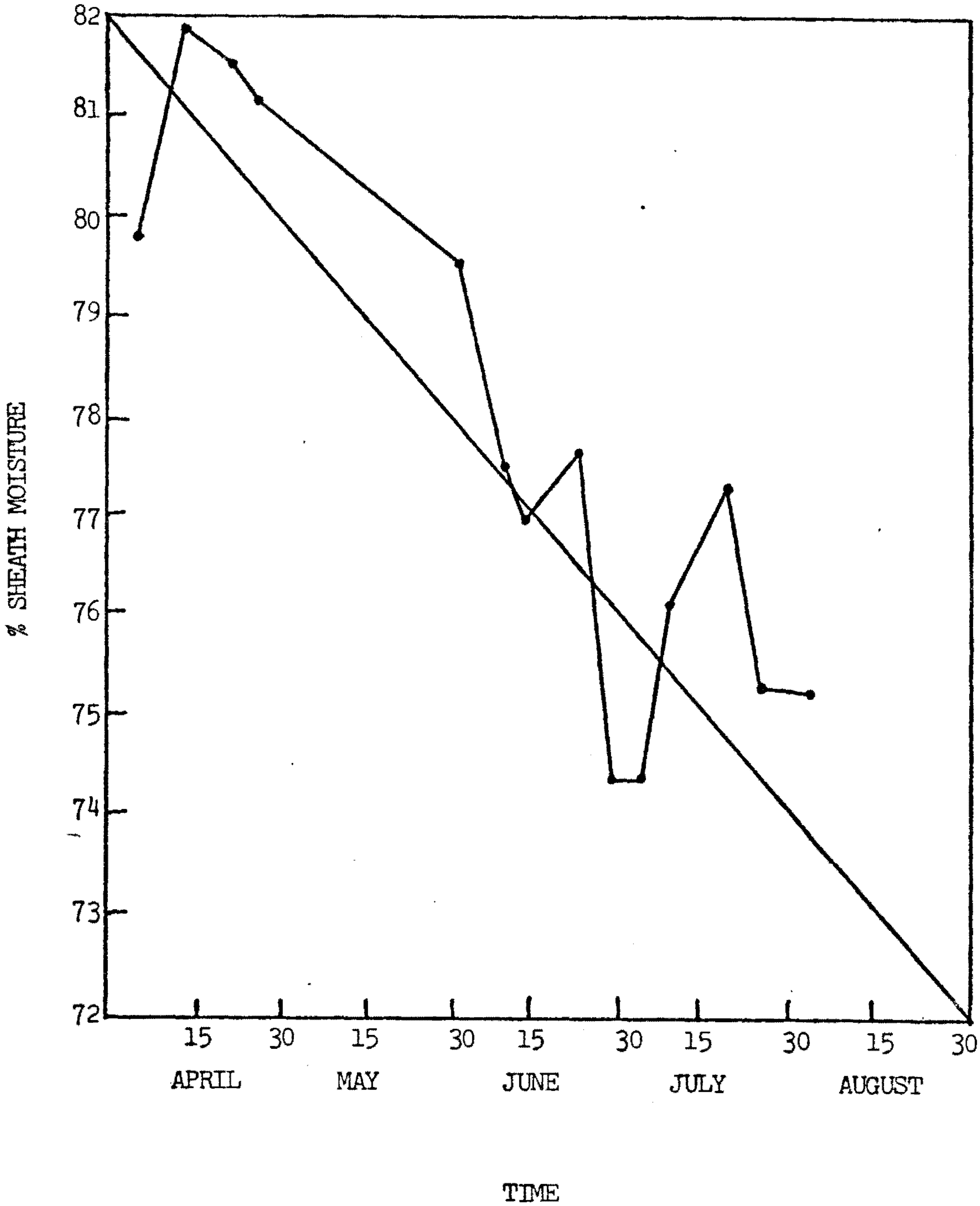
This field was planted on August 13, 1963 and harvested from July 22-29, 1965. The irrigation water used was 60% mill water. The amounts of fertilizer applied were 290 lbs N/acre, 198 lbs P/acre, and 362 lbs K/acre. This was the only field with mixed varieties. Table II shows the result of the crusher juice analysis and yield. This field received approximately the same amounts of nutrients received by Gay 3 through the mill water irrigation. Although the highest amounts of P, K and S in the crusher juice were given by this field, the sucrose percentage in the juice was higher than Gay 3. However the net tons of cane per acre was low compared to the other fields, as a result the field gave the lowest tonnage of sugar per acre, 9.13 tons of cane were required to produce 1 ton of sugar. Under the same high nutrient level, fields Gay 3 and Gay 9 behaved differently. Gay 3 with variety 50-7209 gave the highest yield of cane, but the lowest sucrose per cent in the juice, while Gay 9 with mixed varieties gave a higher sucrose per cent, with a low yield of cane. This indicates that varieties may behave differently under the high nutrient levels. With a low sucrose per cent in field Gay 3 and a low yield of cane in Gay 9, both fields gave a low sugar yield per acre. This behavior indicates the possibility of finding a high nutrient requiring variety that gives a high sugar yield per acre. Figure 2 shows the ripening procedure for this field. Here the sheath moistures were approximately following the diagonal moisture time line. The moisture reached a minimum of about 74%.

TABLE II. ANALYSIS OF CRUSHER JUICE FROM FIELD GAY 9
WITH MIXED VARIETIES (60% MILL WATER)

Samples	Brix %	Pol %	Purity %	Reducing Substances %	Sucrose %	N ppm	P ppm	K ppm	S ppm	Tc/Ts	TSPA	TCPA
1	15.23	13.01	85.4	0.47	10.51	275	236	2560	526	9.49		
2	15.03	12.78	85.0	0.40	12.73	275	250	2880	760	9.01		
3	15.15	13.02	85.8	0.40	12.60	293	226	2560	400	8.85		
4	15.41	13.53	87.7	0.30	13.43	222	234	1840	508	8.22		
5	13.78	11.61	84.3	0.40	12.92	258	132	2460	728	9.50		
6	13.49	11.37	84.3	0.36	11.67	332	176			9.69		
Average	14.68	12.55	85.4	0.39	12.31	276	209	2460	584	9.13	13.35	117.94

Planting date: 8-13-63 Date of harvest: 7-22-29-65

FIGURE 2. RIPENING PROCEDURE FOR FIELD GAY 9, VARIETY: MIXED (60% MILL WATER)



Field Ranch 1

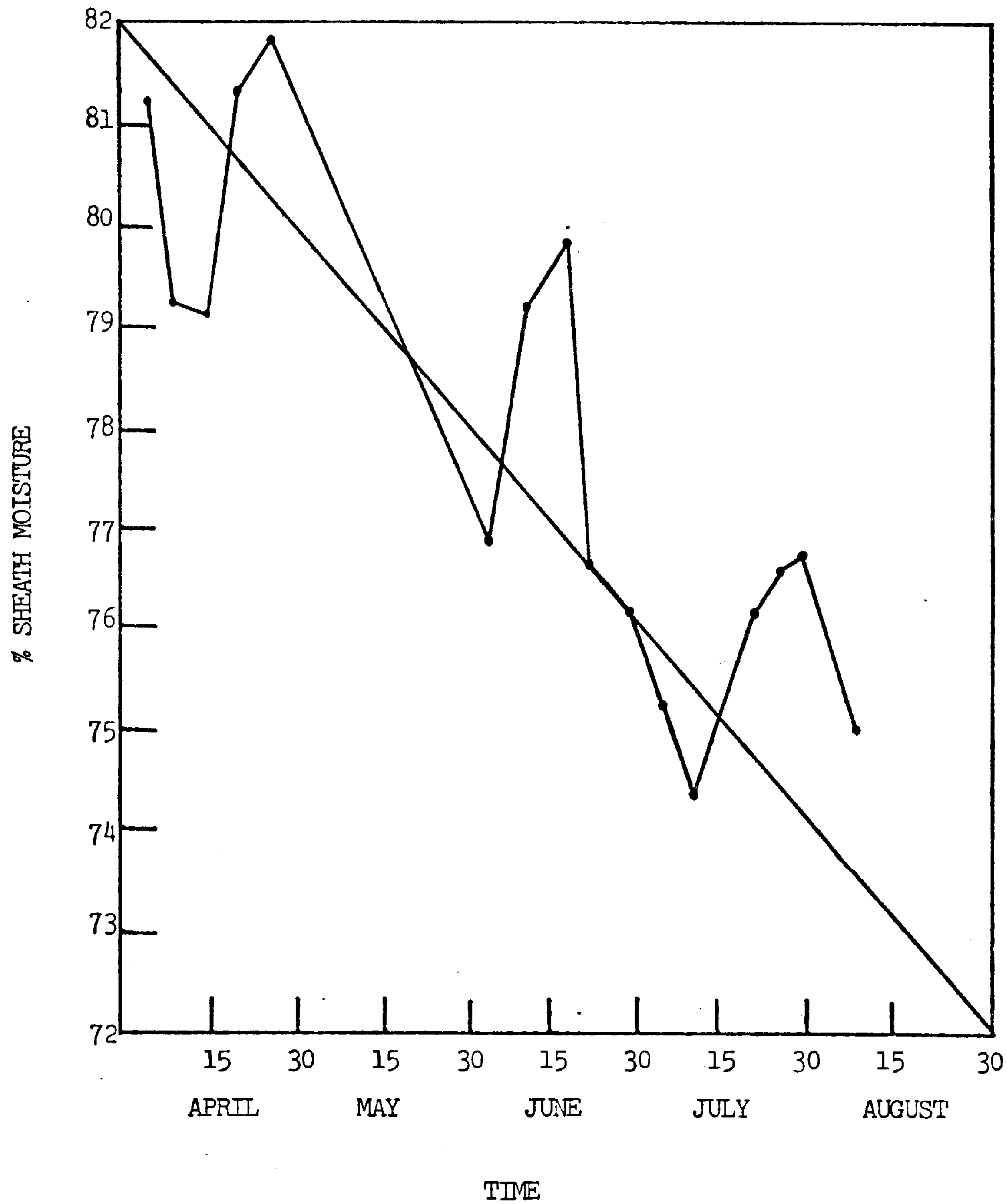
This field was planted on August 3, 1963 and harvested on July 22, 1965. The irrigation water used was 15% mill water. From this 15% mill water the field was supposed to have received about 100 lbs N/acre, 50 lbs P/acre, 300 lbs K/acre and 350 lbs S/acre. This amount plus the applied fertilizer totals 471 lbs N/acre, 253 lbs P/acre and 659 lbs K/acre, far less than the amounts of nutrient applied to the other mill water fields but still in excess of normal practice. Table III shows the result of the crusher juice analysis and yields. Both the purity and sucrose per cent of the juice were higher than 60% mill water fields. Reducing substances were high, again indicating that the reducing substances could not possibly be related to mill water as the cause for low purity and low per cent sucrose. The amounts of P, K, and S were low among the mill water fields, but still high compared to the pump water fields. The result again confirms Borden's statement (1936), that high soil--nutrient availability in the soil=a high percentage of nutrients in the juice. The cane yield was 119.5 tons cane per acre, producing 14.18 tons of sugar per acre. The 15% mill water did not add a lot of nutrient to the soil compared to the 60% mill water. The result was that the per cent sucrose and purity of the juice were not much affected. Figure 3 shows the ripening procedure for this field, in which the sheath moistures closely followed the diagonal moisture time line. This shows that the cane tended to lose moisture more nearly in the normal manner than the 60% mill water cane. It could be said that the higher the level of available nutrients in the soil, especially N, the higher the per cent moisture in the cane.

TABLE III. ANALYSIS OF CRUSHER JUICE FROM FIELD RANCH 1 WITH VARIETY 50-7209 (15) MILL WATER)

Samples	Brix %	Pol %	Purity %	Reducing Substances %	Sucrose %	N ppm	P ppm	K ppm	S ppm	Tc/Ts	TSPA	TCPA
1	15.51	13.66	88.1	0.41	12.90	210	150	1800	464	8.52		
2	15.03	13.07	86.9	0.42	12.13	315	105	1560	418	8.82		
3	14.87	12.61	86.0	0.47	11.70	323	98	1200	504	8.51		
4	15.45	13.72	88.8	0.33	13.34	301	121	2100	446	8.22		
Average	15.21	13.27	87.45	0.41	12.52	287	118	1665	458	8.52	14.18	119.54

Planting date: 8-3-63 Date of harvest: 7-7-22-65

FIGURE 3. RIPENING PROCEDURE FOR FIELD RANCH 1, VARIETY: 50-7209
(15% MILL WATER)



Pump Water Fields

These fields were planted and grown using ordinary pump water for the same variety 50-7209. Average rates of about 315 lbs N/acre, 200 lbs P/acre and 360 lbs K/acre were given as fertilizer. According to the irrigation water analysis (Table IX), these fields received additionally about 50 lbs N/acre, 15 lbs P/acre and 300 lbs K/acre, through the pump water during the growing season. After the leaching of K and the fixation of P and N, small amounts of nutrients will remain in the soil, but in far less amounts than in the mill water fields. The important point here is that most of this amount was supplied as fertilizer which was given during the first 8 months of growth, while the additional mill water nutrients were supplied during the entire growing season. This continuous supply of nutrients will encourage the vegetative growth during the late stages of growth. Das (1931) said the storage capacity of the plant would be increased under these conditions, but less sugar would be stored. The result is that a high cane yield with low sugar is harvested. This was exactly what happened in field Gay 3.

Tables IV, V, VI and VII give the results of the crusher juice analysis and yields for the pump water fields. All the fields gave a high juice purity with a high sucrose per cent. Compared to the mill water fields they gave a far better tonnage of sugar per acre. There was no difference in reducing substances between these fields and the mill water fields. There was not much difference in N in the juice between these fields and the mill water fields, in spite of the large amounts of N that went onto the mill water fields. This could possibly be explained if uptake decreases in the later stages of growth, or if

TABLE IV. ANALYSIS OF CRUSHER JUICE FROM FIELD OPAEULA 9
WITH VARIETY 50-7209 (PUMP WATER)

Samples	Brix %	Pol %	Purity %	Reducing Substances %	Sucrose %	N ppm	P ppm	K ppm	Tc/Ts	TSPA	TCPA
1	15.24	13.42	88.0	0.44	12.00	244	108	1165	8.22		
2	16.58	14.91	89.9	0.38	13.32	306	84	1100	7.40		
3	16.41	14.91	90.9	0.33	12.83	245	120	1200	7.69		
4	14.13	12.85	91.0	0.40	11.40	266	96	1080	7.64		
5	15.15	13.55	89.5	0.34	13.30	300	104	1200	7.62		
6	16.75	15.05	89.8	0.34	13.10	210	64	1050	7.74		
Average	15.71	14.11	89.85	0.37	12.66	262	96	1132	7.72	15.69	119.02

Planting date: 8-11-63 Date of harvest: 7-20-28-65

TABLE V. ANALYSIS OF CRUSHER JUICE FROM FIELD WAIMEA 1
WITH VARIETY 50-7209 (PUMP WATER)

Samples	Brix %	Pol %	Purity %	Reducing Substances %	Sucrose %	N ppm	P ppm	K ppm	Tc/Ts	TSPA	TCPA
1	16.87	15.25	90.4	0.32	13.64	171	79	1280	7.38		
2	16.46	14.57	88.4	0.31	13.34	209	94	1240	7.55		
3	15.59	13.91	89.2	0.27	12.97	176	106	1200	7.31		
4	15.22	13.66	89.7	0.33	13.62	175	104	1560	8.00		
5	16.90	15.31	90.6	0.31	14.80	195	192	1680	7.78		
6	14.74	13.11	88.9	0.30	13.48	200	152	1560	7.88		
7	14.54	13.00	89.4	0.29	13.51	170	168	960	7.77		
Average	15.76	14.12	89.5	0.30	13.62	185	128	1354	7.67	16.17	120.56

Planting date: 7-26-31-63 Date of harvest: 7-28-65

TABLE VI. ANALYSIS OF CRUSHER JUICE FROM FIELD WAIMEA 2
WITH VARIETY 50-7209 (PUMP WATER)

Samples	Brix %	Pol %	Purity %	Reducing Substances %	Sucrose %	N ppm	P ppm	K ppm	S ppm	Tc/Ts	TSPA	TCPA
1	15.16	13.33	87.9	0.41	12.71	218	100	1200	308	8.05		
2	15.26	13.34	87.4	0.39	12.84	242	158	1320	342	8.49		
3	15.36	13.45	87.6	0.45	13.26	226	100	640	354	8.42		
4	15.45	13.37	86.5	0.46	12.94	197	80		436	8.28		
5	15.10	13.29	88.0	0.43	13.24	242	92		456	8.11		
Average	15.27	13.36	87.48	0.43	13.00	225	106	1053	379	8.27	15.12	122.89

Planting date: 8-5-63 Date of harvest: 8-5-16-65

TABLE VII. ANALYSIS OF CRUSHER JUICE FROM FIELDS KAWAILOA 14 AND 15 WITH VARIETY 50-7209 (PUMP WATER)

Samples	Brix %	Pol %	Purity %	Reducing Substances %	Sucrose %	N ppm	P ppm	K ppm	S ppm	Tc/Ts	TSPA	TCPA
1	15.32	13.84	90.3	0.36	13.38	220	105	1050	284	7.66		
2	15.59	13.93	89.4	0.39	13.12	274	97	950	280	7.53		
3	15.28	13.71	89.7	0.43	12.87	206	85	1050	278	7.61		
4	15.72	14.02	89.2	0.41	13.55	251	96	1150	258	8.00		
Average	15.47	13.87	89.70	0.40	13.23	237	96	1050	275	7.70	15.84	121.90

Planting date: 9-11-63 Date of harvest: 8-16-25-65

cane juice is not a suitable indicator for N in the soil. Baver (1960) found that the N composition of the plant at harvest approaches the same values except when comparing late application of higher amounts of N with lower amounts. Das (1931) mentioned that the nitrogenous amino acids brought up by the roots combine with carbohydrates to form new protein material in leaves, meristem tissues, etc. As a result of the ripening procedure, moisture in the soil is decreased and the metabolic activity of the roots and the plant as a whole is thus decreased or brought to a standstill. So less N will be taken up by the roots during ripening, which might be the cause for the N composition at harvest to approach the same value; but the sucrose per cent should come up as a result of ripening. The average yield of cane per acre for the pump water fields was 121 tons. Only an average of 7.8 tons of cane were needed to produce 1 ton of sugar (Table VIII). Figures 4, 5, 6 and 7 show the ripening procedure for these fields.

Figure 8 shows the relationship of sucrose to the amount of N in the crusher juice. The negative correlation coefficient -0.718 is just significant at the 5% level of significance. However, it still agrees with Alexander (1928) and Stanford (1963) that the higher the N level the less the sucrose content.

Figure 9 shows the relationship of sucrose to the amount of K in the crusher juice. The negative correlation coefficient, -0.887 is highly significant at the 1% level of significance. Again we find that the higher the K in the crusher juice the less the sucrose.

Figure 10 shows the relationship of sucrose to the amount of P in the crusher juice. The negative correlation coefficient, -0.832 is

TABLE VIII. AVERAGE CRUSHER JUICE ANALYSIS FOR ALL FIELDS

Field	Purity %	Reducing Substances %	Sucrose %	N ppm	P ppm	K ppm	S ppm	Tc/Ts	TSPA	TCPA
Gay 3 (60% Mill Water)	84.77	0.392	10.84	280	198	2362		9.68	14.36	134.73
Gay 9 (60% Mill Water) (Mixed Varieties)	85.41	0.388	12.31	276	209	2460	584	9.13	13.35	117.94
Ranch 1 (15% Mill Water)	87.45	0.410	12.52	287	118	1665	458	8.52	14.18	119.54
Opaeula 9 (Pump Water)	89.85	0.370	12.66	262	96	1132		7.72	15.69	119.02
Waimea 1 (Pump Water)	89.51	0.304	13.62	185	128	1354		7.67	16.17	120.56
Waimea 2 (Pump Water	87.48	0.428	13.00	225	106	1053	379	8.27	15.12	122.89
Kawailoa 14 (Pump Water)	89.85	0.375	13.25	247	102	1000	282	7.59	16.14	121.66
Kawailoa 15 (Pump Water)	89.45	0.420	13.21	228	90	1100	268	7.80	15.54	122.14

FIGURE 4. RIPENING PROCEDURE FOR FIELD OPAEULA 9, VARIETY: 50-7209
(PUMP WATER)

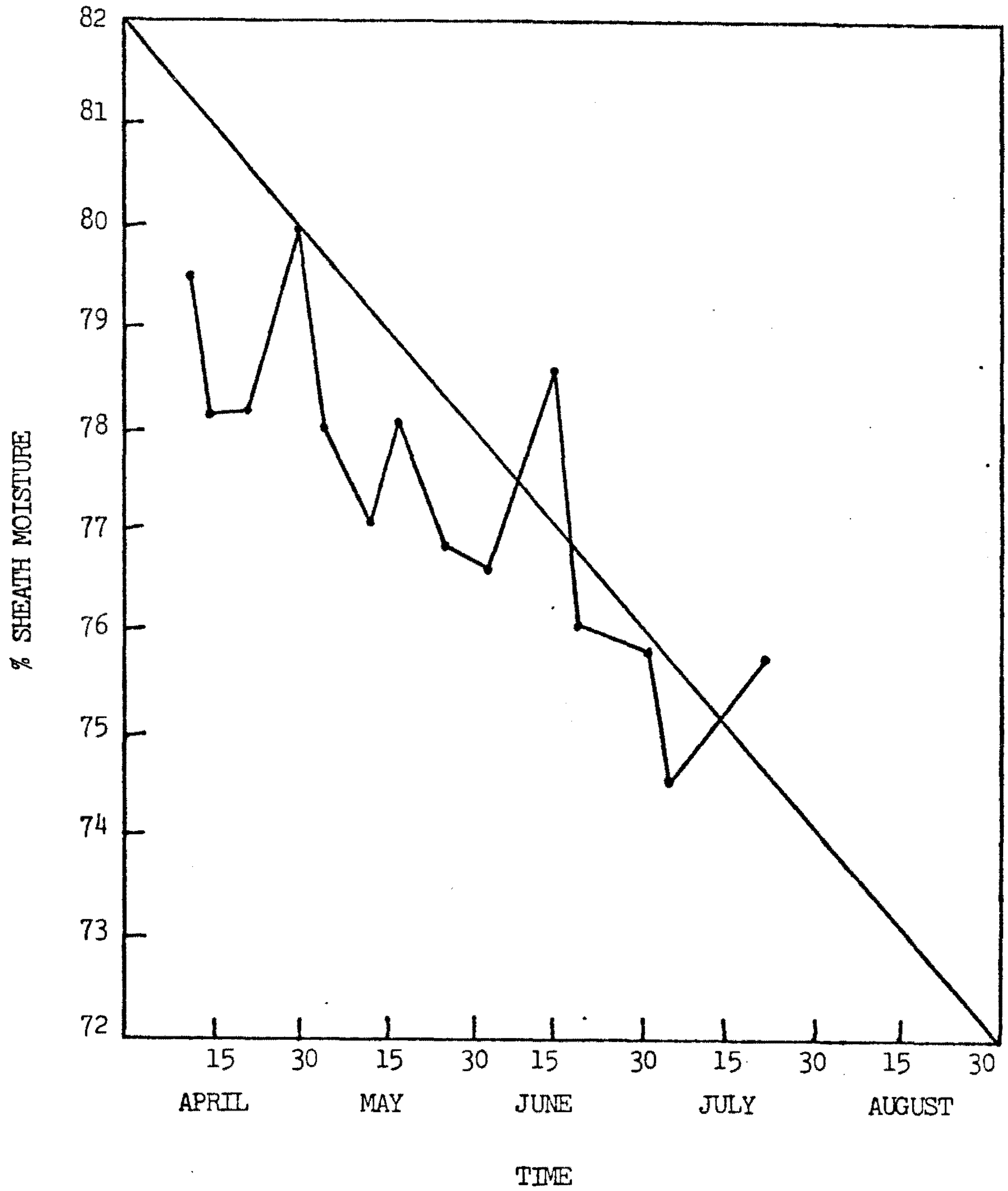


FIGURE 5. RIPENING PROCEDURE FOR FIELD WAIMEA 1, VARIETY: 50-7209
(PUMP WATER)

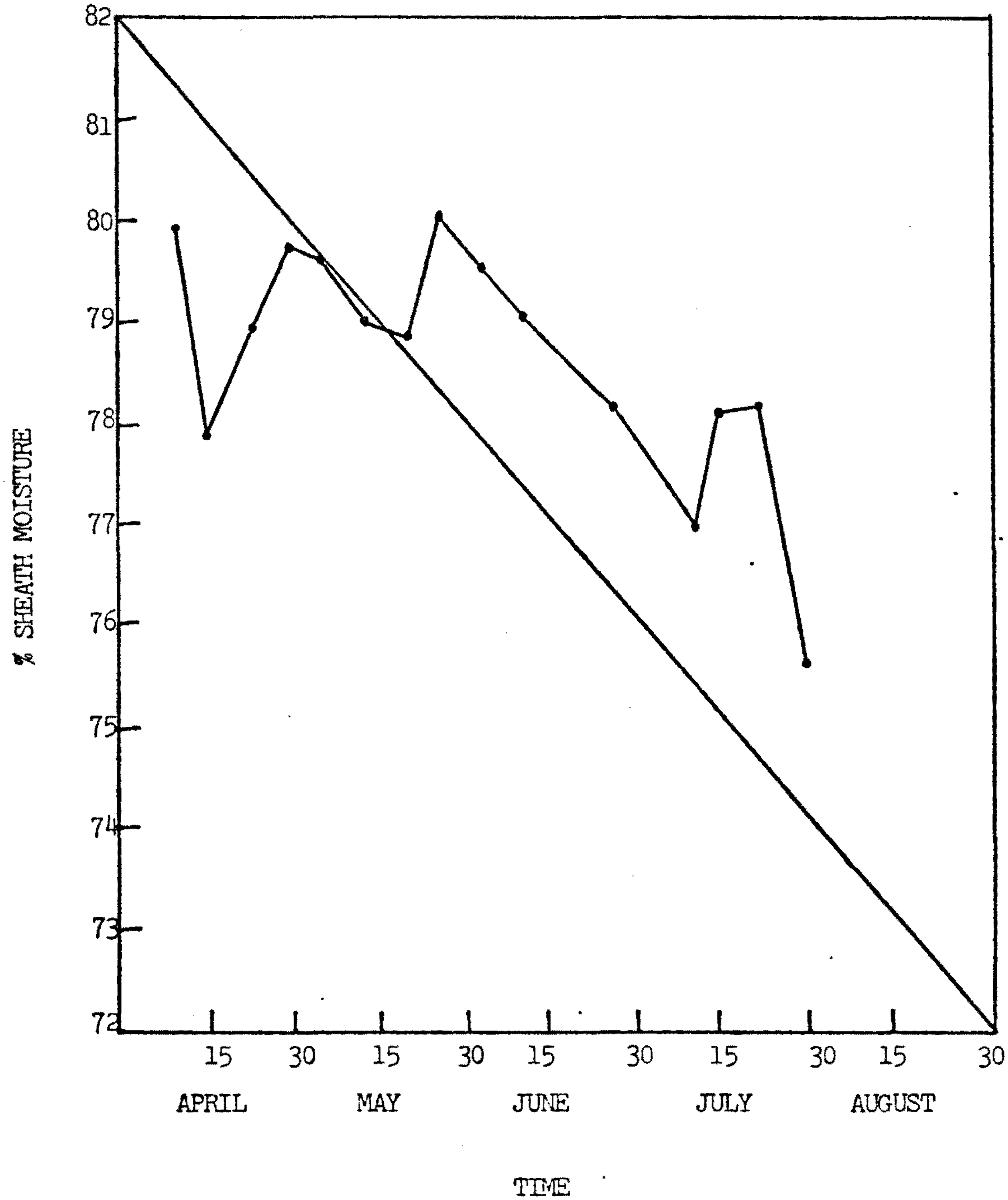


FIGURE 6. RIPENING PROCEDURE FOR FIELD WAIMEA 2, VARIETY: 50-7209 (PUMP WATER)

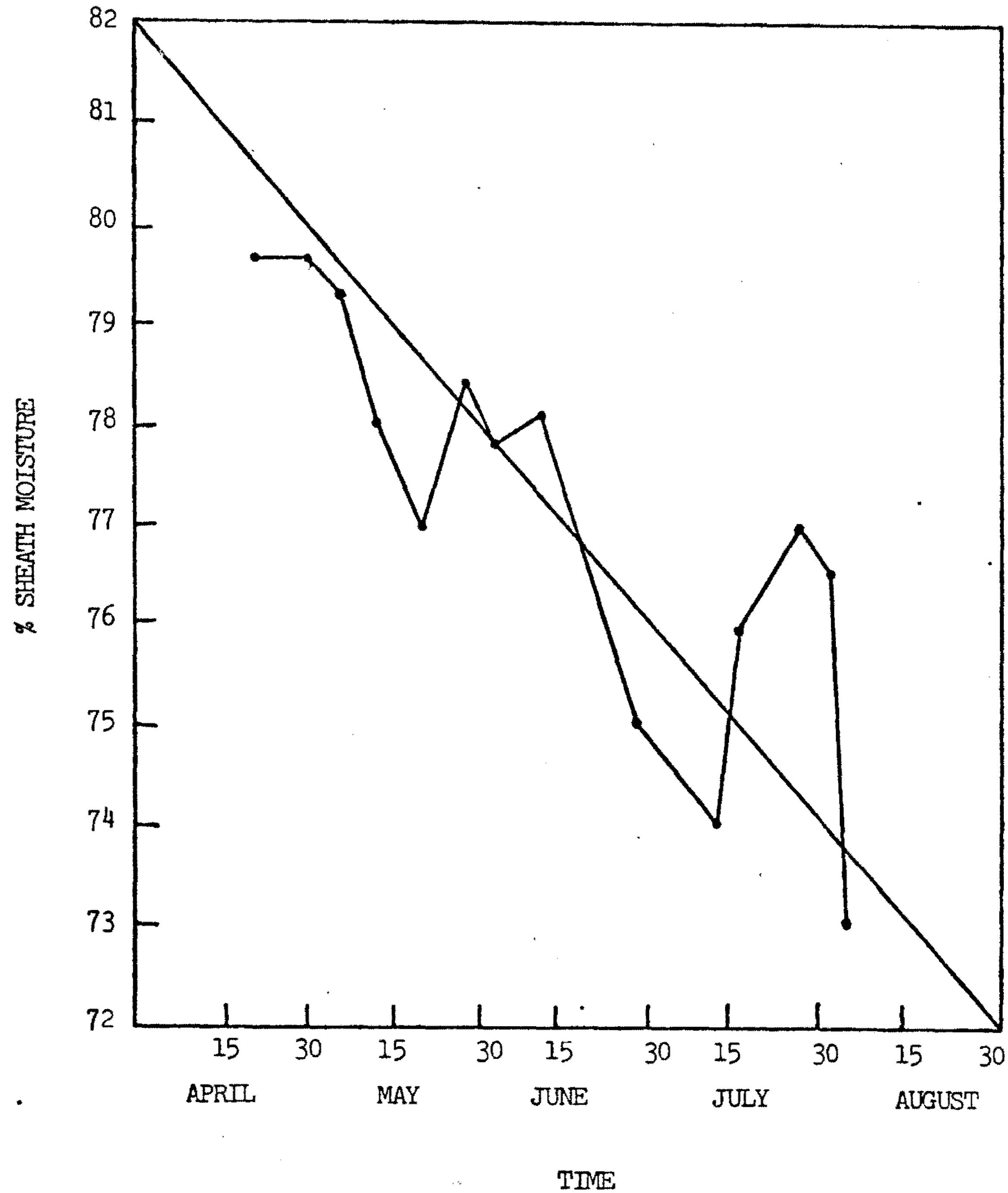


FIGURE 7. RIPENING PROCEDURE FOR FIELD KAWAILOA 14, VARIETY: 50-7209 (PUMP WATER)

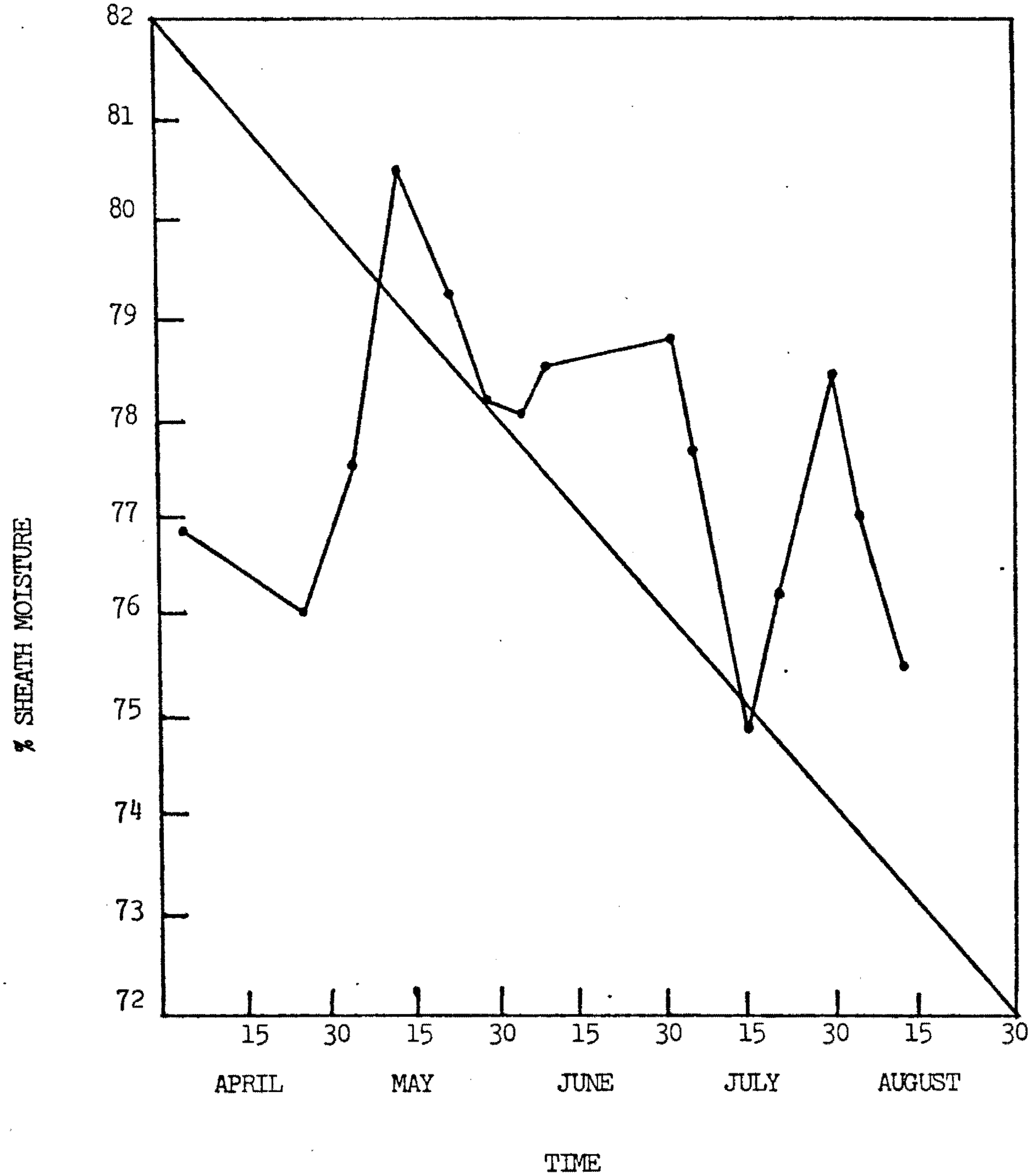


FIGURE 8. THE RELATIONSHIP OF SUCROSE (PER CENT) TO THE AMOUNT OF N IN THE CRUSHER JUICE.

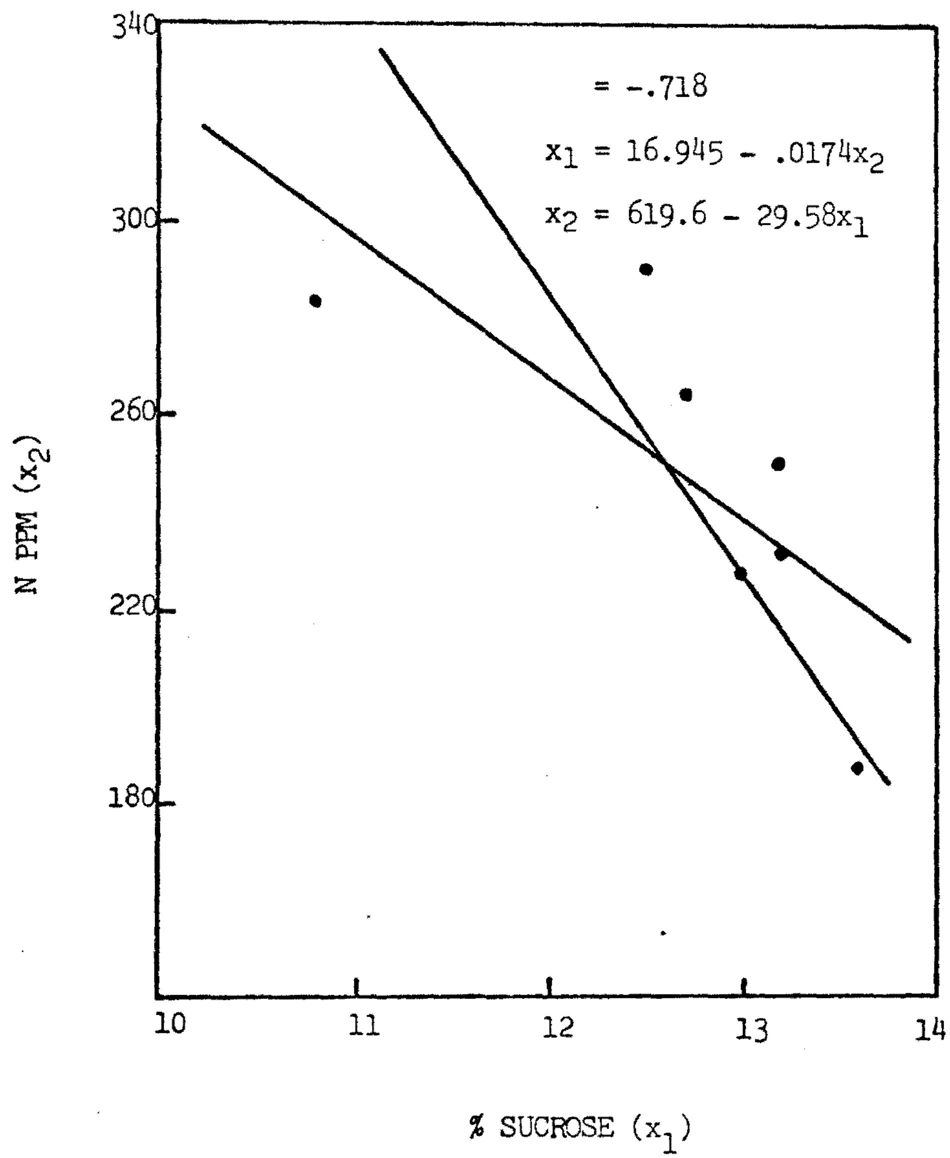


FIGURE 9. THE RELATIONSHIP OF SUCROSE (PER CENT) TO THE AMOUNT OF K IN THE CRUSHER JUICE.

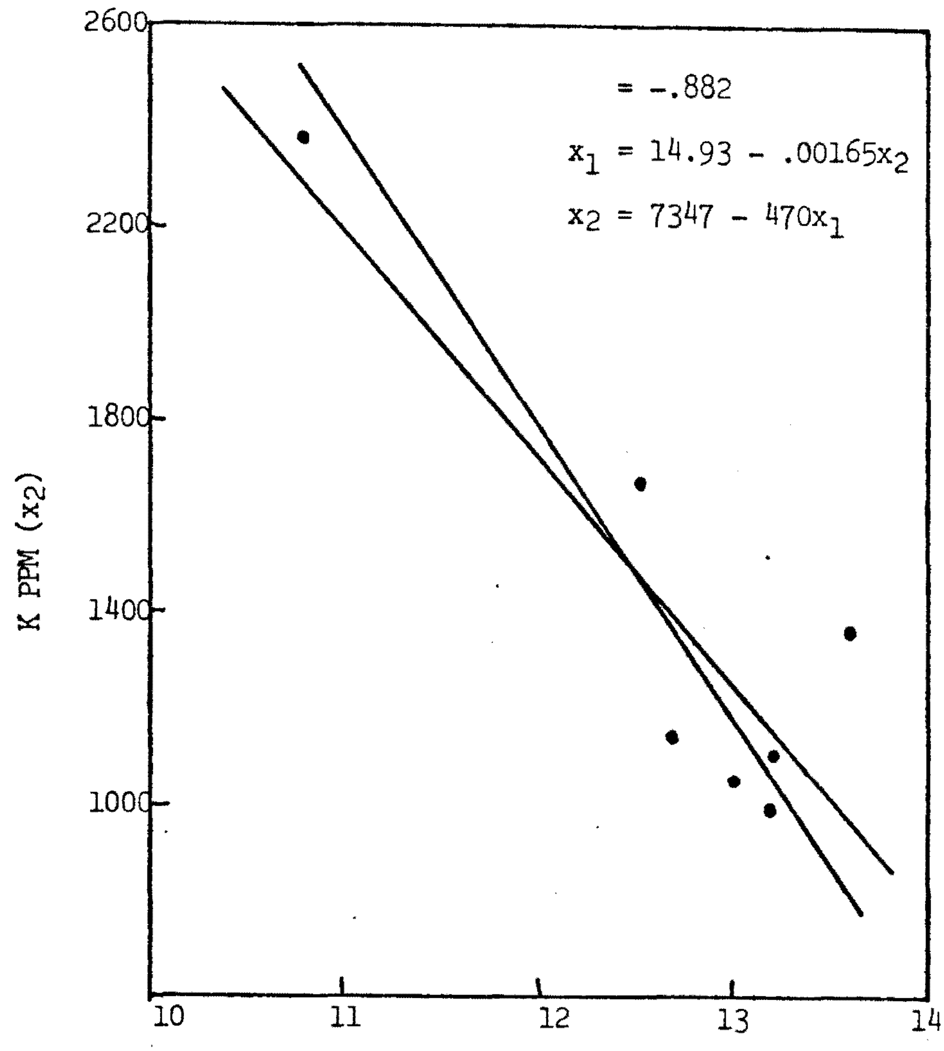
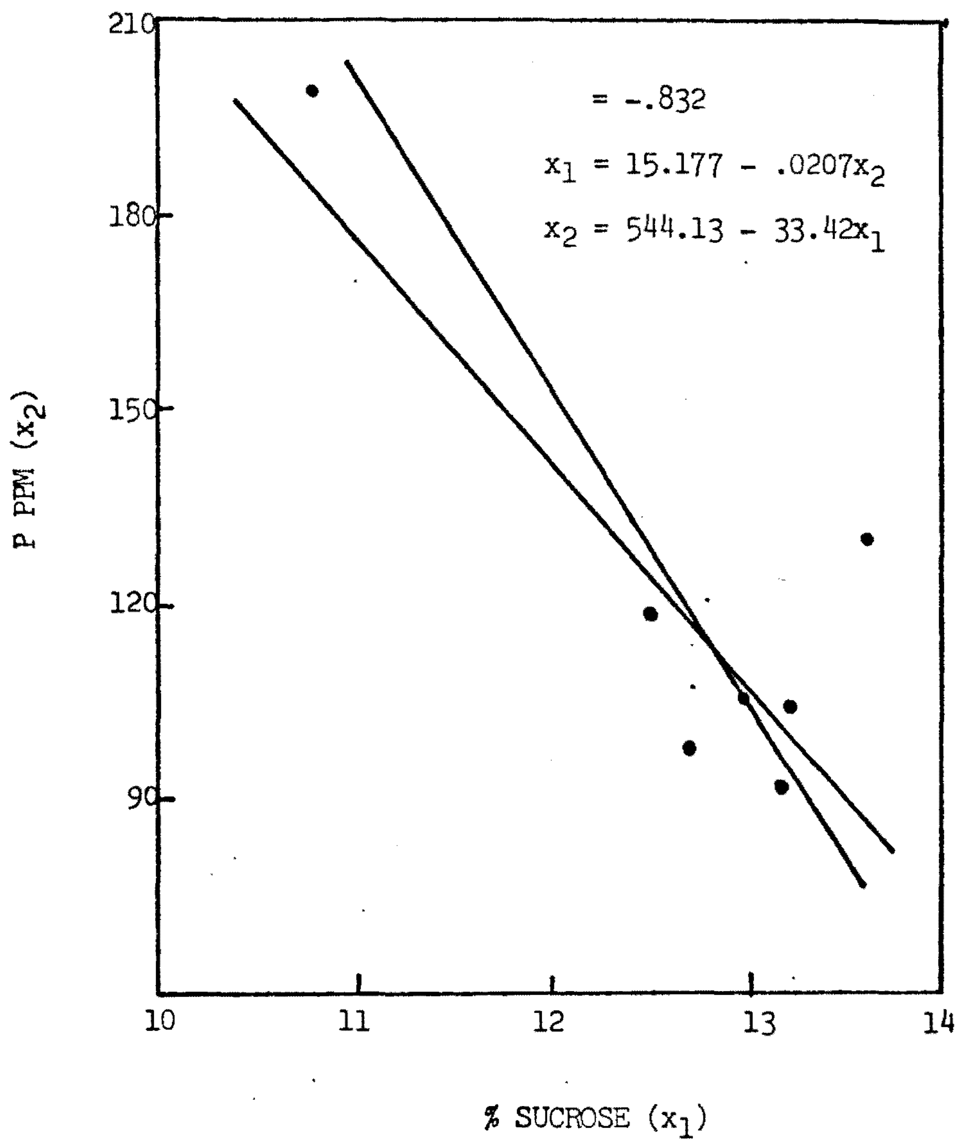


FIGURE 10. THE RELATIONSHIP OF SUCROSE (PER CENT) TO THE AMOUNT OF P IN THE CRUSHER JUICE.



highly significant at the 1% level of significance. This agrees with Borden (1936) that both P and K in the crusher juice showed an adverse relationship to the purity of the juice. From the crusher juice analysis can be seen the high correlation between the amounts of P and K in the soil and their amounts in the crusher juice. Borden (1936) indicated this correlation, while Walker (1922) suggested the possibility of using the P content in cane juice as an indication of the amount of P in the soil.

Irrigation Water Analysis

Table IX shows the results of irrigation water analysis taken from different sources at the Waialua Agricultural Company. The pump water samples were taken from pump No. 1, situated near the ocean, and pump No. 5 far from the ocean. Pump No. 1 gave higher amounts of P, K and S than pump No. 5, while pump No. 5 showed higher amounts of N than pump No. 1. The 100% mill water gave tremendous amounts of N, P, K, and S. The 50% mill water after storage contained higher amounts of nutrients than the 50% mill water before storage. According to this analysis and the calculation on the bottom of Table IX, a field receiving 100% mill water would get 800 lbs N/acre, 350 lbs P/acre, 1800 lbs K/acre and 2300 lbs S/acre through the irrigation water during the growing season. A field receiving 100% mill water does not seem to need any fertilizer. In fact even without applying fertilizer the amounts of nutrients in the soil are still very high compared to a fertilized field receiving pump water. However, mill water fields traditionally have shown a need for N particularly in the early portion of crop, perhaps before enough is supplied in the mill water.

TABLE IX. IRRIGATION WATER ANALYSIS

Type of Water	Samples	N ppm	P ppm	K ppm	S ppm
100% Pump Water Pump No. 1	1	1.04	0.40	10.0	25.6
	2	1.00	0.45	10.2	24.0
	3	1.31	0.50	9.5	24.5
	4	1.13	0.40	11.5	27.0
	Average	1.12	0.44	10.3	25.3
100% Pump Water Pump No. 5	1	1.76	0.38	7.6	8.0
	2	1.60	0.41	6.8	7.8
	3	2.02	0.29	7.1	8.3
	4	1.34	0.37	8.0	7.8
	Average	1.68	0.36	7.4	8.0
100% Mill Water	1	16.40	8.8	46.4	58.4
	2	21.40	8.2	44.5	60.1
	3	17.80	7.5	48.2	58.0
	4	21.55	8.9	45.6	57.5
	Average	19.20	8.4	46.2	58.5
50% Mill Water Before Storage	1	3.40	3.0	24.0	36.8
	2	2.00	3.0	23.1	35.7
	3	3.10	3.2	24.5	36.5
	4	1.50	3.1	22.0	36.0
	Average	2.25	3.1	23.5	36.2
50% Mill Water After Storage	1	10.5	4.7	32.8	40.0
	2	7.3	4.1	33.5	37.6
	3	9.3	4.8	31.9	38.2
	4	9.7	5.1	32.7	40.0
	Average	9.2	4.8	32.7	39.0

Average Irrigation = 6 Acre Inch. Average No. of Rounds = 30.

1 Acre Inch = 27,000 gallons. 6 Acre Inch = 162,000.

6 Acre Inch (30 rounds) = 4,860,000 gallons.

6 Acre Inch (30 rounds) = 40,300,000 lbs of water.

Soil Analysis

Table X shows the result of the soil analysis for field Gay 4 of the Waialua Agricultural Company. The samples were taken after the harvest of cane. The 50% mill water field gave higher results of available P, K and total N. The difference between the two plots was not great. As the samples had been taken directly after harvest; most of the available nutrients might already have been removed from the soil by the crop, fixed in the soil or leached by the irrigation water. It is hard to say whether there was any difference between the bottom and top of the furrow. There was no difference in pH between the two plots, but the pH was a bit higher in case of the top of the furrow.

Varietal Experiment

This varietal experiment was planted at Waialua Agricultural Company. Twenty-six varieties were planted. Each variety was under two different sources of irrigation water (mill water vs pump water). Unfortunately 23 of the varieties under mill water were destroyed before harvest. Only three remained to be compared with the same varieties under pump water. Table XI shows the result of millable cane and juice analysis plus yields. The varieties were 53-1447, 56-4765 and 57-8158. Under pump water, variety 56-4765 gave the highest purity, but the lowest under mill water. The other two varieties gave better purity under mill water. There was no difference between the pump and mill water in case of the per cent reducing substances. Actually the average per cent reducing substances for the three varieties might be higher in pump water than mill water. All the varieties gave more sucrose in the pump water

TABLE X. SOIL ANALYSIS FOR FIELD GAY 4

Field	Furrow	C.E.C. me/100 gm	Available P %	Available K me/100 gm	Total N %	pH
Gay 4 Pump Water	Top	33.80	0.112	0.892	0.140	7.5
	Bottom	33.61	0.102	1.030	0.130	7.3
Gay 4 Mill Water (50%)	Top	34.40	0.120	1.030	0.145	7.5
	Bottom	34.04	0.115	1.550	0.150	7.4

TABLE XI. ANALYSIS OF MILLABLE CANE AND JUICE FOR VARIETAL EXPERIMENT NO. 242 V

Variety	Brix %	Pol %	Purity %	Fibre Contents %	Reducing Substances %	Sucrose %	TCPA	Moisture %	Millable Cane Analysis N ppm	P ppm	K ppm	S ppm
					Pump Water							
53-1447	14.3	11.0	77.0	12.9	0.43	10.80	187.5	73.3	2370	600	1700	1300
56-4765	15.5	12.5	80.1	12.9	0.37	11.46	171.6	73.0	2600	600	2000	900
57-8158	14.8	11.5	77.7	11.7	0.51	11.40	219.8	73.3	2450	500	1280	950
					Mill Water (50%)							
53-1447	14.7	11.4	77.6	12.9	0.36	10.36	227.0	75.7	2410	750	5200	1975
56-4765	15.1	11.4	75.5	16.2	0.58	11.00	175.9	76.0	2430	825	5700	1200
57-8158	15.5	12.4	80.0	11.0	0.32	11.20	196.9	75.7	2410	675	4350	1200

field, showing that the high nutrients in mill water had really affected the sucrose per cent for all the varieties. But the effect was greater on variety 53-1447, and less for variety 56-4765. This might show that the latter can do better under mill water. But this was not the case, because variety 53-1447 gave a very high ton cane per acre under mill water which compensated for the low sucrose per cent, and thus giving the highest ton pol per acre. Variety 57-8158 gave a high tonnage of cane per acre and high sucrose per cent under the pump water showing clearly its unsuitability for a mill water irrigation. All the varieties showed a high per cent moisture in the mill water, with an average of 75.8%, compared to 73.2% moisture in pump water fields. The millable cane analysis showed a high difference in P, K and S between the mill water and pump water. But it did not indicate any difference in the N content.

NPK Experiments

N Application Experiment No. 244-AN

This N application experiment was planted on August 24, 1964 at Oahu Sugar Company. It was harvested on March 4, 1966. The object of the experiment was to find the amounts of nitrogen needed for variety 50-7209 in a mill irrigation water field. The treatments consisted of three levels of N; A_1 = zero N/acre, A_2 = 200 lbs N/acre and A_3 = 400 lbs N/acre. All the treatments received 216 lbs P_2O_5 and 400 lbs K_2O per acre. The treatments were replicated five times. Unfortunately three of the replicates were destroyed and only two replicates were taken into consideration. The level A_3 = 400 lbs N/acre was taken for one replicate only. The size of the microplot used for the samples was 5.5 ft x 5 ft. There was much splitting of cane in all plots which healed later. Much silt was deposited in the cane line by the mill water. Regardless of treatment all plots were green in appearance. Table XII shows the results of analysis of millable cane plus green leaves for yield and juice. To an observer's eye there was a clear trend for the different levels of N application, but the analysis of variance did not show any significant difference. Actually the small numbers of samples and blocks made the F-value very high, as a result of which it is difficult to get a significant difference. However the analysis of variance can still be a good guide for comparison, since we are interested in the trends and general correlations rather than in arriving at the significance attached to the specific differences observed. Table XIII shows no difference between the zero N and the 200 levels in the sucrose content, but there was a difference between these levels and the 400 N level. The 400 N level gave a lower per cent sucrose. It also gave the highest cane yield per acre. So we find that although the high amount of N decreased the per cent sucrose, it increased the tonnage of cane per acre. The yield for the 400 N level was 191 tons of cane per acre. According to Stanford and Ayres (1964), 2 pounds of N are required for 1 ton of millable cane. Thus the requirement for 191 tons was about 400 lbs N, exactly what was applied. But, as the experiment was conducted in a mill water field we assume that more than this amount was supplied through irrigation, and the total amount was far more than was required. The cane tonnage per acre increased as the N application increased, and the difference became clear between the zero N and 400 N

TABLE XII. MILLABLE CANE, GREEN LEAVES AND JUICE ANALYSIS FOR N APPLICATION EXPERIMENT NO. 244-AN

Treat-ment and Plot No.	Purity	Fibre	Reducing Substances	Sucrose	Estimated TCPA	Moisture	Juice			Millable Cane and Green Leaves		
							N	P	K	N	P	K
	%	%	%	%		%	ppm	ppm	ppm	ppm	ppm	ppm
10 A1	84.3	10.0	0.45	12.10	154.0	76.0	450	210	1470	3100	820	11,100
16 A1	85.3	11.0	0.62	12.67	174.0	75.6	400	210	1970	2300	770	7,200
11 A2	88.8	11.5	0.39	12.88	182.0	72.0	450	250	2200	2400	830	7,000
17 A2	84.7	10.8	0.65	12.64	189.0	74.6	490	190	2000	2800	700	8,700
12 A3	82.2	10.5	0.75	11.84	191.0	76.6	520	190	2320	2900	770	9,000

TABLE XIII. ANALYSIS OF VARIANCE FOR N APPLICATION EXPERIMENT NO. 244-AN

Source of Variation	D.F.	Mean Squares: Sucrose %	TCPA	N ppm Juice	N ppm Millable Cane and Green Leaves
Blocks	1	0.02	121.5	1.7	150
Treatments	2	0.43	407.17	451.7	650
0 vs 200 + 400	1	0.02	784.09	653.4	75
200 vs 400	1	0.84	30.25	250.0	1225
Error	2	0.085	51.5	101.6	1950
			N.S.		

level. The N application had a positive relationship to the cane yield and a negative relationship to the sucrose per cent. N in the juice showed a slight increase as N application increased. In the millable cane and green leaves there was also an increase in N as application increased, with the exception of plot 10 A_1.

P Application Experiment No. 243-AP

The field was planted on August 24, 1964 at Oahu Sugar Company and harvested on March 3, 1966. The object of the experiment was to find the amounts of phosphorus for variety 50-7209 in a mill irrigation water field. The treatments consisted of two levels of phosphorus B_1 = zero P/acre and B_2 = 216 lbs P/acre. Both treatments received 300 lbs N and 400 lbs K per acre. Again only two replicates out of five were considered in this study. There were many split stalks in the cane which had healed in all plots. Much silt was deposited in the cane line by mill water. Conditions were very difficult for microplot sampling due to the vigorous root development in the silt deposit. Table XIV shows the results of the juice and yield analysis of millable cane plus green leaves. The analysis of variance (Table XV) does not show any significan results but the trend can be seen in Table XIV. The P in the juice, millable cane and green leaves were both higher in B_2 than in B_1, especially in the juice. This agrees with Borden's (1936) indication that a low phosphate percentage in the juice would be likely to indicate a low availability in the soil, and a high juice content a high soil availability. Treatment B_2 gave higher sucrose per cent, purity and tonnage of cane per acre over treatment B_1. The zero P treatment gave a higher percentage of reducing substances than the 216

TABLE XIV. MILLABLE CANE, GREEN LEAVES AND JUICE ANALYSIS FOR P APPLICATION EXPERIMENT NO. 243-AP

Treatment and Plot No.	Purity	Fibre	Reducing Substances	Sucrose	Estimated TCPA	Moisture	Juice			Millable Cane and Green Leaves		
							N	P	K	N	P	K
	%	%	%	%		%	ppm	ppm	ppm	ppm	ppm	ppm
7 B1	78.1	10.4	0.91	10.34	207.0	75.8	430	210	1700	2900	860	11,300
9 B1	80.4	9.9	0.82	11.50	201.0	77.2	530	220	2000	3300	850	12,900
6 B2	82.5	10.2	0.75	12.19	245.0	75.5	440	240	2080	2500	880	9,200
8 B2	82.4	11.4	0.57	12.72	217.0	75.3	500	260	2150	3300	930	12,600

TABLE XV. ANALYSIS OF VARIANCE FOR P APPLICATION EXPERIMENT NO. 243-AP

Source of Variation	D.S.	Mean Squares			
		Sucrose %	TCPA	P ppm Juice	P ppm Millable Cane and Green Leaves
Blocks	1	0.71	289	22.0	40
Treatments	1	2.35	729	122.5	250
Error	1	0.11	121	3.0	90
			N.S.		

P treatment. This shows that an increase in the reducing substances had nothing to do with the increase in the level of P.

K Application Experiment No. 242-AK

The field was planted on August 24, 1964 at Oahu Sugar Company, and harvested on March 4, 1966. The object of the experiment was to find the amounts of potash required for variety 50-7209 in a mill irrigation water field. The treatments consisted of three levels of K, C_1 = zero K/acre, C_2 = 300 lbs K/acre and C_3 = 600 lbs K/acre. All the plots received 216 lbs P and 300 lbs N per acre. Out of five only two replicates were considered in this thesis. Much silt was deposited in cane line by mill water in most of the plots. There was much split cane in all plots which had healed. Regardless of treatments all plots were green in appearance. Table XVI shows the result of analysis of juice and yield of millable cane plus green leaves, for this experiment. The analysis of variance (Table XVII) does not show any significant results. The K (ppm) in the juice was very high in the 600 K treatment, yet the treatment gave the highest juice purity. This recalls the crusher juice analysis, and might indicate that the high K in the juice had nothing to do with the low purity. Although the highest sucrose per cent (13.58) was given by plot $6C_3$, it is difficult to say that C_3 gave better sucrose per cent than C_1. But the sucrose per cent for C_3 was definitely better than C_2. So we see that the K application did not lower the per cent sucrose but it did increase the ton cane per acre. According to Samuels _et al_. (1952), it appeared that the application of K fertilizer will not appreciably increase the sucrose content of the cane, if it does not increase cane tonnage yield

TABLE XVI. MILLABLE CANE, GREEN LEAVES, AND JUICE ANALYSIS FOR K APPLICATION EXPERIMENT NO. 242-AK

Treat-ment and Plot No.	Purity	Fibre	Reducing Substances	Sucrose	Estimated TCPA	Moisture	Juice			Millable Cane and Green Leaves		
	%	%	%	%		%	N ppm	P ppm	K ppm	N ppm	P ppm	K ppm
1 C1	85.3	10.5	0.51	13.22	188.0	74.0	480	200	1860	3000	770	6,900
4 C1	85.8	11.8	0.59	13.50	183.0	72.8	460	220	2100	2600	770	5,700
2 C2	82.2	10.5	0.74	12.56	200.0	76.6	420	190	1950	2600	770	8,200
5 C2	85.8	10.5	0.75	13.00	182.0	75.2	460	210	1980	2700	720	6,300
3 C3	86.9	11.2	0.42	12.85	190.0	74.6	460	210	2860	2800	770	8,400
6 C3	87.2	11.1	0.51	13.58	200.0	74.8	470	210	2560	2700	720	5,800

TABLE XVII. ANALYSIS OF VARIANCE FOR K APPLICATION
EXPERIMENT NO. 242-AK

Source of Variation	D.F.	Mean Squares			
		Sucrose %	TCPA	K ppm Juice	K ppm Millable Cane and Green Leaves
Blocks	1	.3504	28.16	15	5420
Treatments	2	.1752	45.5	36272	522
0 vs 300 + 600	1	.1752	75.0	17040	1021
300 vs 600	1	.1892	16.0	55500	23
Error	2	.02602	98.17	3700	240
			N.S.		

at the same time. Actually it was clear from Table XVI that the K fertilizer did increase the tons of sugar per acre. The increase in K (ppm) as the K application increased was more evident in the juice than in the millable cane and green leaves.

Experiment 138 VXAN

This field was planted on August 28, 1963 at Kahuku Plantation Company. It was harvested on August 3, 1965. The object of the experiment was to determine the optimum timing and amount of nitrogen fertilization for varieties 49-3533 and 50-7209. It was a randomized block design with 10 treatments arranged as follows:

Treatment	Time of Application of N-lbs				(Totals (lbs)		
	1 week	2½ month	5 month	8 month	N	P_2O_5	K_2O
X	0	0	0	0	0	100	122
A	50	50	75	50	225	100	122
B	100	0	75	50	225	100	122
C	0	100	75	50	225	100	122
D	0	50	100	75	225	100	122

Each of the above treatments was given to two varieties, 49-3533 and 50-7209, for a total of 10 treatments. The treatments were replicated twice. Table XVIII gives the results for the millable cane and juice analysis. The reducing substances and sucrose per cent were very roughly estimated. There was no difference in purity between the two varieties. But there were differences between the treatments. The zero N treatment gave a higher purity than the 225 lbs N treatments. Table XIX shows the analysis of variance for tons cane per acre, pol per cent cane,

TABLE XVIII. MILLABLE CANE, AND JUICE ANALYSIS FOR EXPERIMENT NO. 138 VXAN

Variety	Treatment and Plot No.	Estimated Reducing Substances %	Estimated Sucrose %	Purity %	Pol % Cane	TPPA	TCPA	Moisture %	Millable Cane N ppm
50-7209	9X1	0.41	13.8	85.7	14.9	13.5	90.6	69.7	1100
	17X1	0.33	10.6	86.1	15.0	12.6	80.3	69.0	1000
	6A1	0.52	10.7	83.6	14.4	19.0	131.8	72.0	1600
	12A1	0.48	11.5	83.3	13.4	19.3	144.0	70.3	1500
	3B1	0.45	11.8	83.3	14.7	17.1	116.7	72.7	1600
	29B1	0.25	12.3	82.6	13.1	18.1	138.0	73.0	1700
	5C1	0.25	12.0	82.1	13.1	17.6	134.4	70.7	1500
	15C1	0.30	12.6	78.3	10.8	15.5	143.5	71.7	1700
	10D1	0.30	12.0	83.9	14.3	18.8	131.3	73.3	2300
	16D1	0.27	12.3	83.4	14.1	18.0	127.2	71.0	1600
49-3533	2X2	0.40	12.6	86.0	15.2	9.6	63.1	70.3	900
	13X2	0.37	11.0	83.1	13.8	9.4	68.2	69.2	900
	1A2	0.46	11.0	85.0	15.4	18.0	116.8	71.7	1400
	11A2	0.35	12.3	83.9	14.4	17.7	122.7	74.3	2200
	8B2	0.46	10.4	85.3	15.9	20.4	128.2	70.0	1900
	14B2	0.38	10.9	83.4	14.0	17.0	122.1	73.0	2100
	4C2	0.42	12.0	83.5	14.5	19.2	132.6	69.7	1300
	18C2	0.60	9.0	86.0	15.1	19.5	129.0	69.7	1400
	7D2	0.49	10.9	83.7	15.2	18.2	119.6	71.7	1300
	30D2	0.38	12.0	84.0	14.1	19.0	134.3	74.3	2300

TABLE XIX. ANALYSIS OF VARIANCE FOR EXPERIMENT NO. 138 VXAN

Source of Variation	D.F.	Mean Squares			
		TCPA	Pol % Cane	TPPA	N ppm Millable Cane
Blocks	1	97.68	4.80**	1.75	9.7
Treatments	9	1142.64**	1.66*	20.65**	26.7
Variety	1	512.07*	4.80**	0.04	0.1
Application N	1	9318.24**	1.03	163.59	147.0**
Timing N	3	55.83	1.09	0.30	13.0
Var x AN	1	117.13	2.57*	12.49**	20.0
Var x TN	3	56.27	1.09	2.94	2.3
Error	9	52.22	0.42	0.96	11.14

* = P at .05 ** = P at .01

ton pol per acre and N ppm in millable cane. Table XX shows the summary of averages. Variety 50-7209 gave a significant gain in tons cane per acre over variety 49-3533. But variety 49-3533 gave a higher pol per cent cane which was highly significant. There was no significant difference between the varieties in the case of ton pol per acre. There was no significant difference between the two varieties in N in millable cane. According to Stanford and Ayres (1964) different sugarcane varieties possess the same internal N requirements per ton of dry matter at near maximum yield of cane. The application of 225 lbs N/acre gave a highly significant gain in tons cane per acre, and N in millable cane over zero N. There was no significant difference in pol per cent cane between 225 N and zero N. For timing of N application there was no significant difference between all the results. This could be due to the fact that all the fertilizer was applied in all the treatments in the first 8 months. Usually when some of the N fertilizer is delayed after the 10th month, it might affect the juice quality. Ortega _et al_. (1963) found that juice purity and sugar yields per acre were highest when all the nitrogen was applied within the first 4 months, irrespective of whether the amount was divided into two or three applications. The effect of the delayed application of N on the quality of juice was also mentioned by Stanford (1963). In Table XX under N application the 225 N gave more moisture in the cane than zero N. This was actually the case with all the previous experiments. The more the N, the more the vegetative growth and more succulent the plant becomes.

TABLE XX. SUMMARY OF AVERAGES FOR EXPERIMENT NO. 138 VXAN

Variety	TCPA	Pol % Cane	TPPA	Millable Cane N ppm	Moist-ure %
1. Variety					
50-7209	123.8	13.8	16.9	1560	71.3
49-3533	113.7	14.8	16.8	1570	71.4

Plots	Lbs N/A	TCPA	Pol % Cane	TPPA	Millable Cane N ppm	Moist-ure %
2. N Application						
X	0	75.6	14.7	11.1	970	69.65
ABCD	225	129.5	14.2	18.3	1700	71.75

Plot	Time of Application of N-lbs				TCPA	Pol % Cane	TPPA	Millable Cane N ppm	Moist-ure %
	1 week	2½ month	5 month	8 month					
3. N Timing									
A	50	50	75	50	128.8	14.4	18.5	1700	72.0
B	100	0	75	50	126.3	14.4	18.2	1800	72.1
C	0	100	75	50	134.9	13.4	18.0	1500	70.4
D	0	50	100	75	128.1	14.4	18.5	1900	72.5

SUMMARY AND CONCLUSION

This investigation was undertaken to study the reasons for the adverse effects of mill water used in irrigation of sugarcane in Hawaii. The following samples were studied: a.) crusher juice samples from fields receiving different amounts of mill water, b.) soil samples from pump and mill water fields, and c.) irrigation water samples from different sources. The following experiments, considered to be related to the problem were also studied: a.) a varietal experiment grown under mill and pump water, b.) a timing and application of N experiment, and c.) NPK application experiments.

Cane yield, sugar yield, and juice quality were measured. The nutrient content of the juice and millable cane were also measured and compared with the nutrient content of the irrigation water and soil. The results could be summarized as follows:

1. A 100% mill water irrigation was found to supply 1 acre with approximately 800 lbs N, 350 lbs P, 1800 lbs K and 2300 lbs S, during the 2-year growing season.
2. In the crusher juice analysis, it was found that the higher the amount of nutrients in the juice, the higher the cane yield and lower the sucrose per cent. This was not the case with the other experiments where 600 lbs K/acre gave better yield of cane and juice purity over treatments of zero K and 300 K per acre. Also the 216 lbs P/acre gave higher sucrose per cent and ton cane per acre over zero P. Only the 400 N lbs/acre, gave lower per cent sucrose and higher ton cane per acre than zero N and 200 N per acre.

3. A definite positive relationship was shown between both P and K in the irrigation water and P and K in the crusher juice. Although the relationship between N in the irrigation water and N in the crusher juice was not very clear, there was a slight positive relationship.
4. There was a highly significant negative relationship between P and K in the crusher juice and the sucrose content. But this relationship can only hold true when the amounts of P and K are very high. The same relationship exists between N in the juice and sucrose per cent. But with N the relationship holds true with large and small amounts too.
5. Timing of N application during the first 8 months had no effect on yield and sucrose per cent.
6. There was no relationship between the amounts of nutrients in the juice or the fertilizer applied and the per cent of reducing substances.
7. The higher the nutrient content of the juice, the higher the per cent moisture in the cane.
8. The mill water deposited a lot of silt on the fields, but there was no effect on pH.

Different varieties can behave differently under high nutrients. A large varietal experiment might help us to select a variety that can do well under mill water. If the mill water is supplied to the field during the first season, and then replaced by ordinary pump water, this might decrease its adverse effects. Fields receiving a large amount of mill water might do better without N, P, and K fertilizers. A few pounds of N fertilizer in the first 4 months only might make it better.

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